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US 5225712 A US 4400659 A US 4193005 A

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(54) Abstract Title
Wind energy system

(57) A control unit 11 senses the phase voltages for each phase of a utility grid 2, and the control unit 11 also senses the three phase sum active and reactive powers of the grid 2. A microcomputer (24) in the control unit 11 processes the measured data to determine the maximum output power Plim which wind turbine driven generators 13, connected to the grid 2, can be permitted to generate. The limit value is sent from control unit 11 to a control processor 12 which changes the operating parameters of the wind turbines 13 to limit their output power to below Plim. The wind turbines 13 may be adjustable with respect to wind direction according to the output from control processor 12. The problem of over-voltage supply on a weakly loaded grid is thereby avoided.

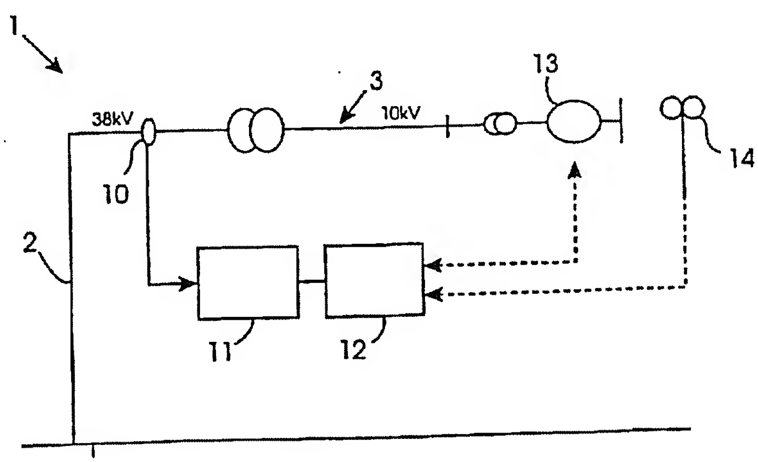


Fig. 1

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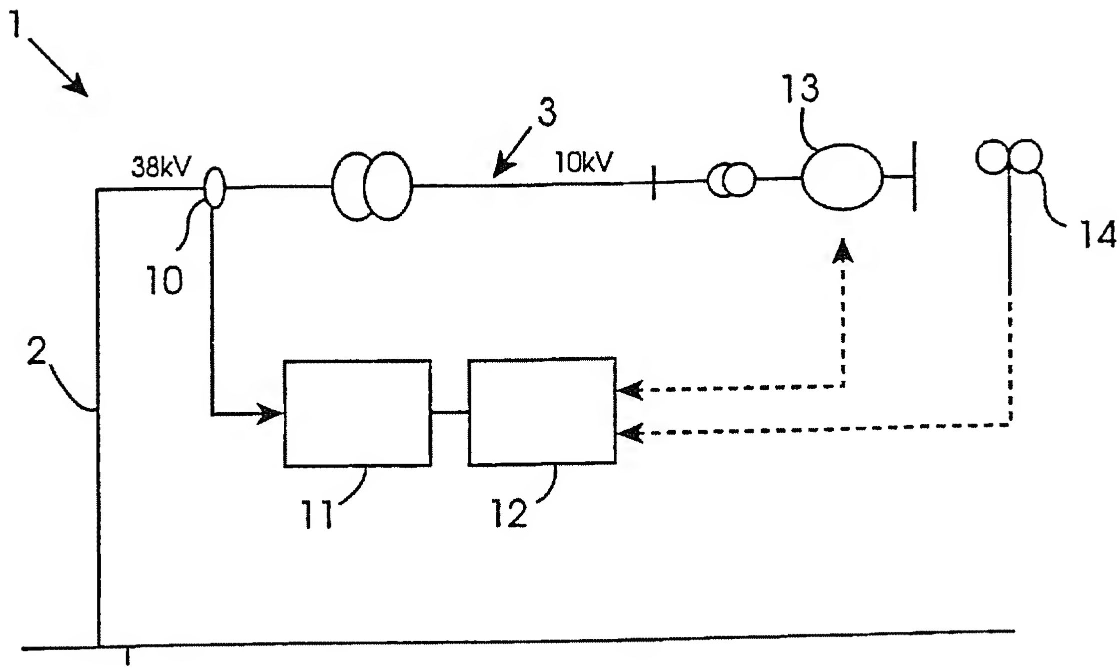


Fig. 1

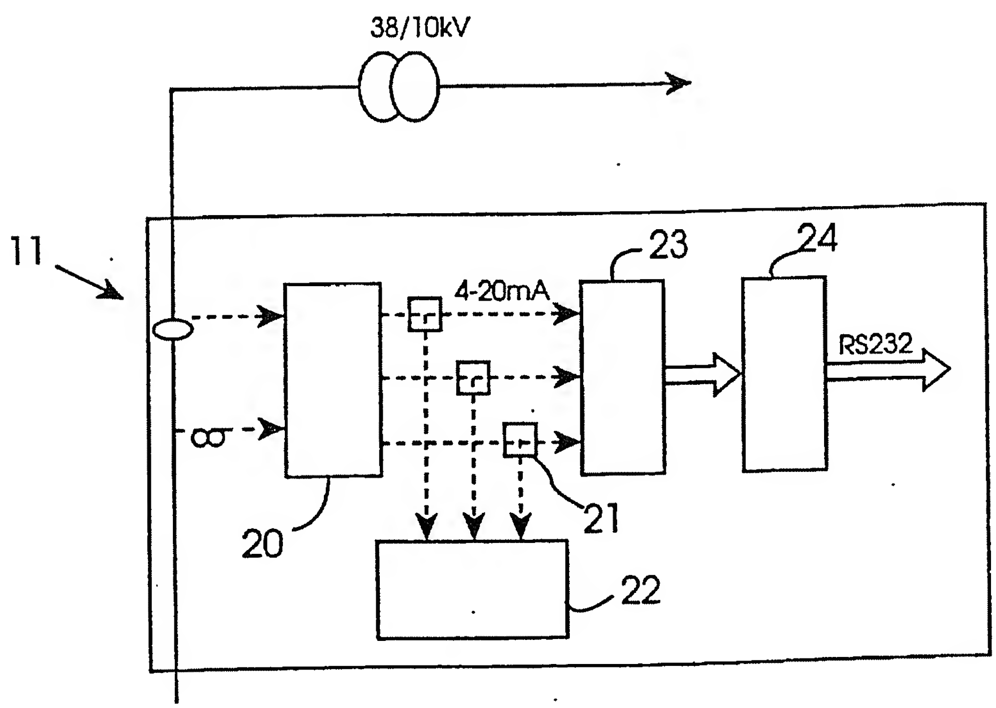


Fig. 2

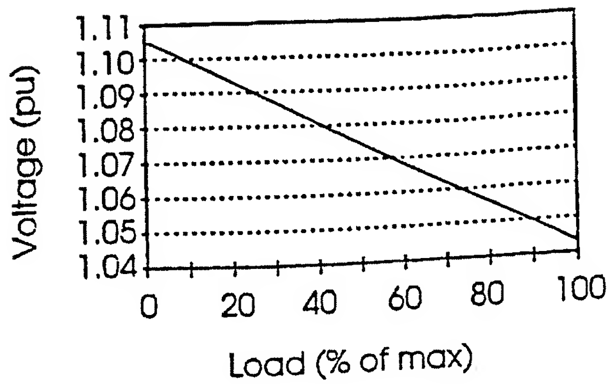


Fig. 3

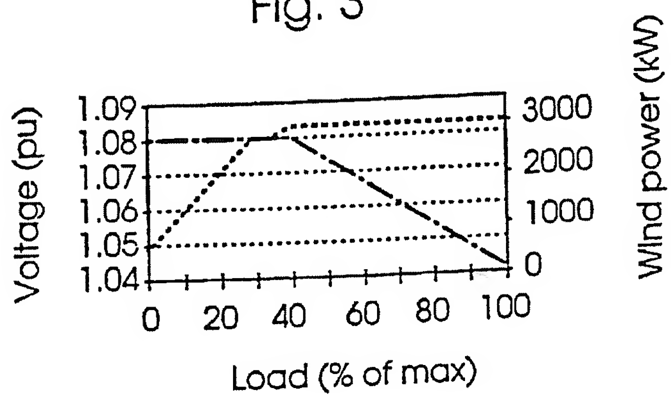


Fig. 4

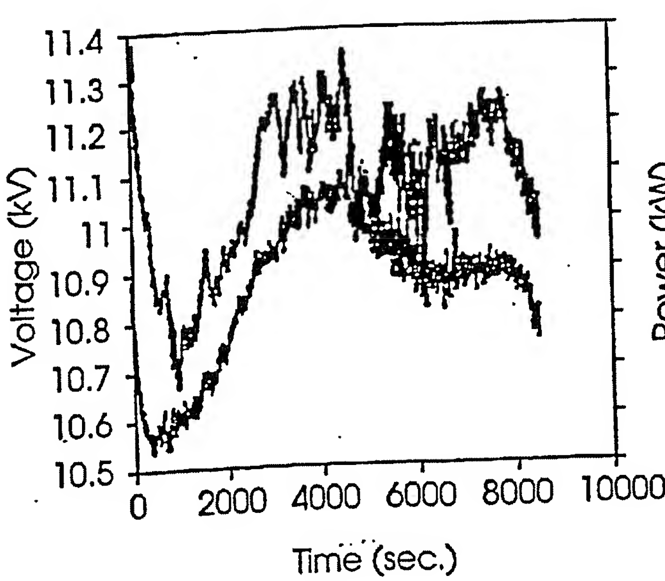


Fig. 5

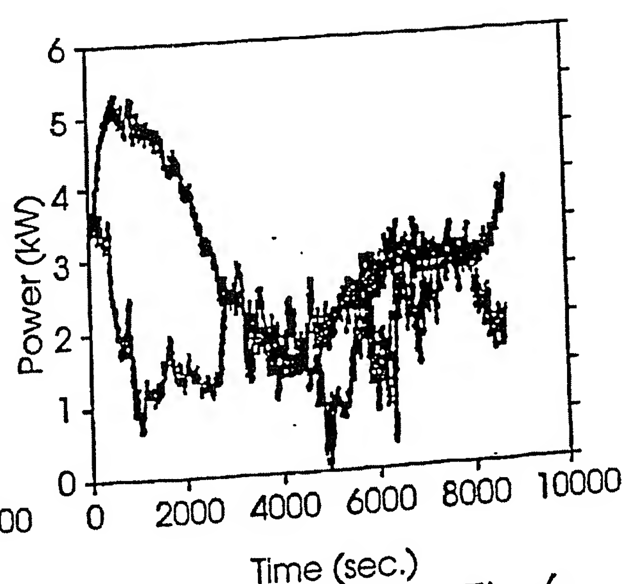


Fig.6

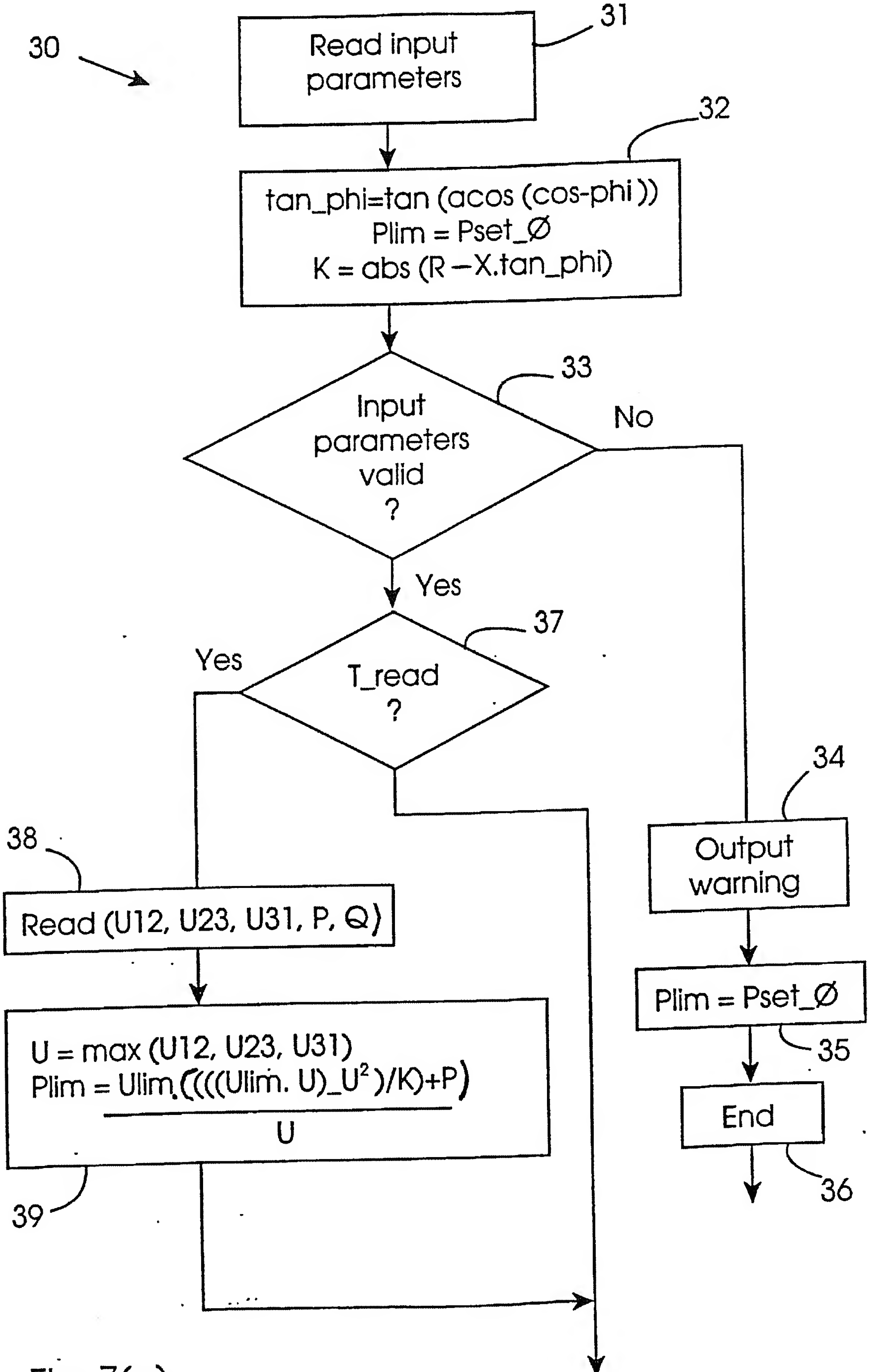
30
Read input parameters
31
tan_phi=tan (acos (cos-phi))
Plim = Pset_Ø
K = abs (R – X.tan_phi)
32
Input parameters valid ?
33
No
Yes
T_read ?
37
Yes
Output warning
34
Plim = Pset_Ø
35
End
36
Read (U12, U23, U31, P, Q)
38
U = max (U12, U23, U31)
Plim = Ulim.((((Ulim. U)_U²)/K)+P) / U
39

Fig. 7(a)

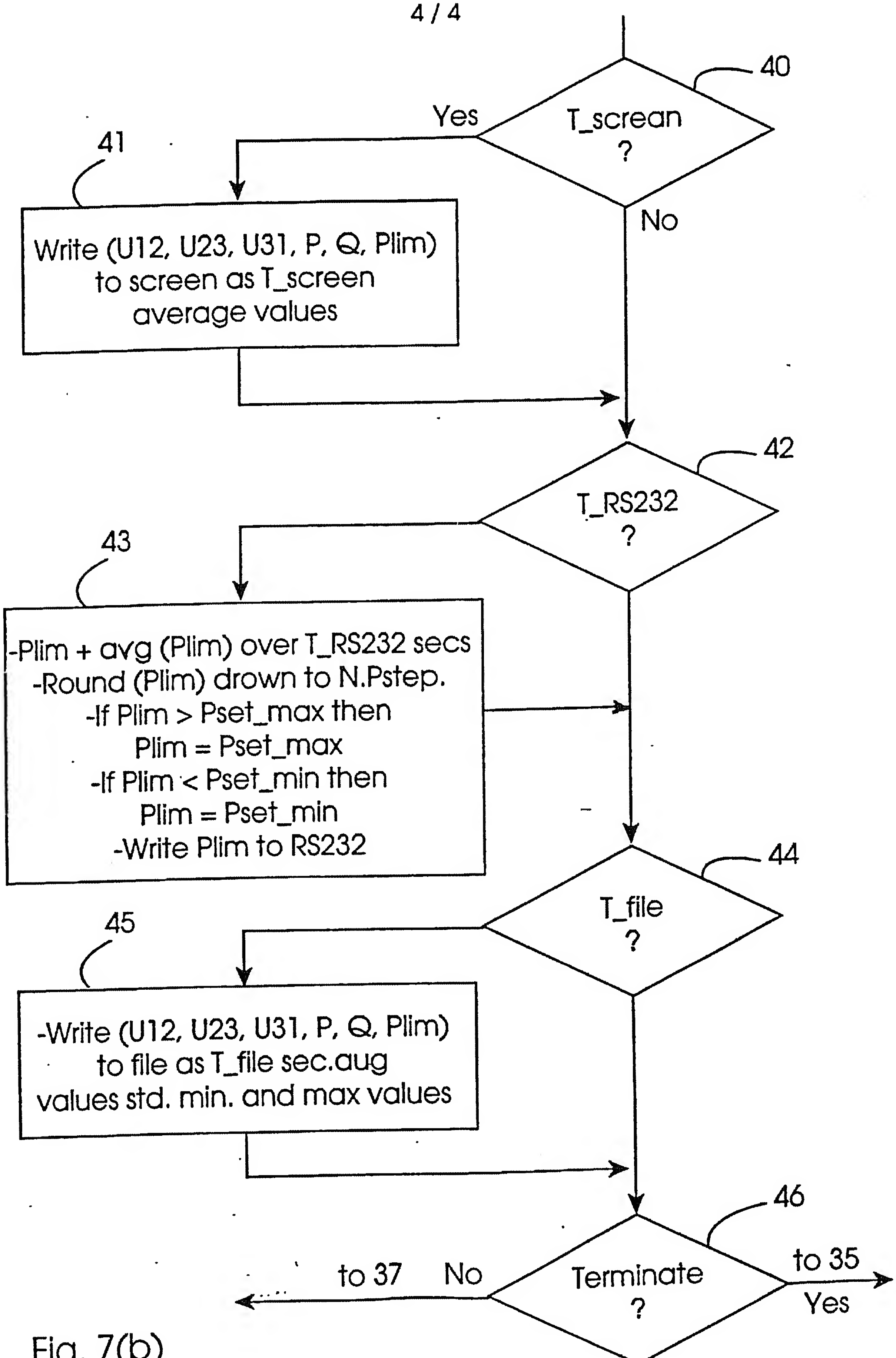
40
T_screan
?
Yes
No
41
Write (U12, U23, U31, P, Q, Plim)
to screen as T_screen
average values
42
T_RS232
?
43
-Plim + avg (Plim) over T_RS232 secs
-Round (Plim) drown to N.Pstep.
-If Plim > Pset_max then
Plim = Pset_max
-If Plim < Pset_min then
Plim = Pset_min
-Write Plim to RS232
44
T_file
?
45
-Write (U12, U23, U31, P, Q, Plim)
to file as T_file sec.aug
values std. min. and max values
46
Terminate
?
to 37
No
to 35
Yes

Fig. 7(b)

"A Wind Energy System"

The invention relates to a wind energy system, particularly for supply of electrical power to relatively weak grids.

Various proposals have been made for preventing over-voltage on a grid in circumstances where the wind energy system has a high output and the grid load is weak. These proposals include regulation of reactive power, management of the load, and energy storage. In one example, if a suitable water system is available, and the cost is not too high in relation to the electrical benefits, energy storage may be used by pumping water during peak supply periods. However, there are many situations in which the reactive power may not be regulated, it is not possible to sufficiently manage the load, and hydroelectric systems are not available for energy storage.

The invention is therefore directed towards providing a system and method for overcoming the problems of over-voltage supply to weak grids.

According to the invention, there is provided a wind energy system for supply of electrical power to a utility grid, the system comprising:-

a wind turbine comprising means for connection to the grid;

adjustment means for adjusting wind turbine output power;

means for sensing grid voltage and outputting a grid voltage signal; and

a controller comprising:-

an input interface for receiving the grid voltage signal;

a processor comprising means for processing the grid voltage signal to generate an output signal to limit wind turbine output power; and

an output interface for transmitting said output signal to the adjustment means.

By sensing grid voltage and processing this signal, the system can dynamically in real time respond to grid conditions in a way which maintains grid supply quality in a very simple manner. Very little additional installation expense is required and because sensing and processing is performed in real time, control is achieved to optimise wind energy system output while at the same time maintaining utility grid supply quality.

In one embodiment, the sensing means also comprises means for sensing grid active power and the processor comprises means for processing a signal representing grid active power and the grid voltage signal to generate the output signal. By sensing grid active power in addition to grid voltage, very accurate control can be achieved.

Preferably, the sensors comprise means for sensing three line voltages of the grid and the processor comprises means for using the maximum grid voltage value to determine the wind turbine maximum output power. By sensing all of the three voltage levels and only processing the maximum level, comprehensive control is achieved.

In one embodiment, the processor is initialised by storage of a default value for the maximum wind turbine output power and the processor comprises means for validating input parameters and setting the maximum wind turbine output power to the default value if validation is negative. This is an important default mechanism to ensure continuity of control for grid supply quality.

Preferably, the processor comprises means for determining that validation is negative if the absolute value of the short-circuit grid resistance minus the grid reactance times the tangent of the power factor angle is zero. This is a simple filtration mechanism to ensure accuracy of the processing.

In one embodiment, the controller input interface comprises voltage and impedance transducers comprising means for converting sensed values to current signals. Such transducers are very effective and reliable.

In another embodiment, the input interface further comprises an analog to digital converter comprising means for converting the analog current signals to digital signals suitable for processing by the processor. Preferably, said analog to digital converter comprises analog input modules and a bus terminal which polls the input modules for signals and routes digital signals to the processor. These are very simple and reliable circuits.

In one embodiment, the system further comprises current to voltage converters connected to convert the current signal outputs of the transducers to digital signals for monitoring of the measured values. Such monitoring is very important for test purposes as it allows early detection of any faults which may arise.

In one embodiment, the processor comprises means for operating in timed loops for performing screen and storage file data dumps.

Preferably, the data dumps are performed by initially calculating average values for the parameters over the period between the dumps and writing the average values.

In another embodiment, the processor comprises means for validating the wind turbine maximum power output value by determining that it lies within a tolerance range before outputting to the wind turbine.

Preferably, the output interface comprises a separate control processor connected to the processor and being programmed to output a control signal to the adjustment means.

The invention will be more clearly understood from the following description of some embodiments thereof, given by way of example only with reference to the accompanying drawings in which:-

Fig. 1 is a schematic diagram illustrating a wind energy system of the invention;

Fig. 2 is a diagram illustrating a voltage control unit of the system in more detail;

Figs. 3 to 6 inclusive are diagrams illustrating results achieved by the voltage control unit; and

Figs. 7(a) and 7(b) are together a flow diagram illustrating operation of the voltage control unit.

Referring to the drawings, and initially to Fig. 1 there is illustrated a wind energy system 1 of the invention. The system 1 is shown connected to a utility grid 2 at a 38/10 kV transformer Point of Common Coupling (PCC). The system 1 comprises a tap 10 on the grid 2 and connected to a voltage control unit (VCU) 11. The VCU 11 is connected to a control processor 12, which is in turn connected to control five 600 kW wind turbines 13. The wind turbines 13 are adjustable with respect to wind direction to control system output according to the output of the control processor 12. The control processor 12 is also connected to a meteorological station 14 to receive weather condition inputs for control purposes.

Referring particularly to Fig. 2, the VCU 11 is now described in more detail. The tap 10 comprises voltage and current transformers and is mounted at the 38 kV side of the 38/10 kV transformer.

Transducers 20 are connected to the tap 10 for conversion of the measured values to 4-20 mA DC signals. There is one transducer for each voltage signal $U_{12}$, $U_{23}$, and

$U_{31}$ and a single transducer for grid active power P and reactive power Q. The transducers 20 provide one signal for the three phase sum active power and the three phase sum reactive power, and one for each of the three line voltages. The transducers have an accuracy similar to class D.2 or better and a response time less than 300 msec.

The VCU 11 also comprises current to voltage converters 21 which convert the 4-20 mA signals to voltage signals in the range 0-10 V. These voltage signals appear at sockets 22 for monitoring purposes.

An A/D converter (ADC) 23 samples the 4-20 mA DC signals and converts them to digital signals compatible with a microcomputer. The converter 23 comprises two Interbus S™ analog input modules and a bus terminal which polls the input modules for signals and routes the digital signals to a microcomputer 24. The microcomputer 24 is programmed for reading the digital data, storing time series of sample data, calculating the maximum allowable wind farm output power Plim, and transmitting this limit value as a signal on an RS232 port to be read by the control processor 12. The sampling rate per channel is at least two times the response frequency of the transducers 20.

In operation, the system 1 provides power to the grid 2. The highest voltage level is at the Point of Common Coupling (PCC) of the system i.e. at the 38/10 kV transformer. The graph of Fig. 3 illustrates how the voltage level depends on the consumer load level at the grid. If the load is less than 40% of the maximum level, the voltage level at the PCC may become critically high i.e. above 1.08 pu. It is at this point that the VCU must limit the system output. The graph of Fig. 4 illustrates how the VCU operates. It causes the control processor 12 to limit the maximum output power from the system so that the voltage is kept below 1.08 pu even if the load is reduced below 40%. In this example, as the load drops below 40% the system power output is reduced from c. 3000 kW to c. 500 kW. This action prevents the voltage from rising above 1.08 pu.

Referring now to Figs. 5 and 6, example voltage and power outputs with respect to time are given. In this example, the system has a maximum output of 5 MW and is connected to the grid with an estimated short circuit impedance of R = 2.5 Ohm and X = 2.5 Ohm. There is a voltage limit of 11.25 kV. As is clear from these diagrams, the VCU limits the output power to a little over 5 MW during hours with high load and down to 1 MW during hours with low load.

Referring now to Fig. 7, the manner in which the microcomputer 24 of the VCU 11 operates is now described. The VCU 11 reads the measured values of active power, reactive power, and line voltages and calculates the maximum permitted wind farm output, Plim. The following two tables set out the input parameters and the symbols used.

**Table 1 Description of input parameters for VCU.**

| **Parameter** | **Description** | **Default value** |
|---|---|---|
| Pset_0 | default setting for Plim | 2400 kW |
| Pset_min | minimum value for Plim | 0 kW |
| Pset_max | maximum value for Plim | 3000 kW |
| Pstep | discretisation step for Plim | 10 kW |
| T_read | "loop-time" for reading measurement signals | 0.025 sec |
| T_screen | "loop-time" for writing to screen | 1 sec |
| T_RS232 | "loop-time" for writing to RS232 | 10 min |
| T_file | "loop-time" for writing to file | 10 min |
| Cos_phi | wind farm power factor | 0.95 |
| R | short-circuit resistance of grid seen from wind farm | 7.0 ohm |
| X | short-circuit reactance of grid seen from wind farm | 73.5 ohm |
| Ulim | maximum permitted voltage level | 41.0 kV |

**Table 2 Description of symbols.**

| Symbol | Description |
|---|---|
| Plim | maximum permitted output power from the wind farm |
| U12 | measured line voltage at the high voltage side of the transformer at the wind farm |
| U23 | measured line voltage at the high voltage side of the transformer at the wind farm |
| U31 | measured line voltage at 38 kV side of the transformer at the wind farm |
| P | measured sum active power at 38 kV side of the transformer at the wind farm |
| Q | measured sum reactive power at the high voltage side of the transformer at the wind farm |
| U0 | calculated voltage in case of zero output form the wind farm |
| U | maximum of U12, U23 and U31 |
| N | integer number |

The process flow is indicated generally by the numeral 30. In step 31 the processor reads in the input parameters as set out in Table 1 above. In step 32 the processor determines the tangent of the system power factor angle phi, sets the maximum power Plim to the default Pset-0, and determines an actual system impedance K as the absolute value (abs) of (R – X.tan_phi). R and X are set in Table 1 above, the values being received from the grid utility.

In step 33, the processor validates the input parameters. This is based on the value of K. If zero, a warning signal is outputted in step 34, Plim is set to Pset-0 in step 35, and processing ends in step 36. This validation ensures that the inputted values R and X for the grid are within reasonable limits and ensures that numerical errors do not arise in subsequent processing.

The loop time for reading measurement signals is determined in step 37 and at each such time the processor in step 38 reads $U_{12}$, $U_{23}$, $U_{31}$, P, and Q. The maximum line voltage U is determined in step 39 and U is then used to determine Plim. Other factors used are Ulim, R and X (as represented by K), all of which are pre-set grid

values. The measured values used are U and P. Q is represented indirectly in the system power factor angle used to determine K. It is not a particularly important parameter because it is assumed that the system power factor is constant. Thus, the primary sensed parameters are U and P. The processor in step 39 determines Plim as a safe value consistent with maximising the system output for commercial purposes.

At the loop time for writing to the screen as determined by step 40, in step 41 the processor writes $U_{12}$, $U_{23}$, $U_{31}$, P, Q, and Plim to the screen as average values for the T_screen period.

At the loop time for writing to the RS232 port (every 10 minutes) as indicated by the step 42, the processor in step 43 determines the average Plim over the period and rounds it down to an integer times the discretisation step. It then performs validation checks to set the value at the maximum or minimum values if it is outside the tolerance range. It then writes the value to the RS232 port from whence it is transmitted to the control processor 12. The control processor 12 is programmed to change the operating parameters of the wind turbines 13 to limit the output power to below Plim.

As indicated by the step 44, at the loop time for writing to file (10 minute periods), the processor writes $U_{12}$, $U_{23}$, $U_{31}$, P, Q, and Plim to the file as average values over the time period.

If the process is to terminate, Plim is set as Pset_0 in step 35 or alternatively the process flow returns to step 37.

The VCU 11 operates also as a data acquisition system. The captured data includes the sum active power, sum reactive power, and the three line voltages, as well as the calculated maximum permitted output power. This data is stored as accessible text files, one for each month, containing time series with 10 minutes average value and 10 minutes standard deviation values, and minimum and maximum values. This data is very important for data analysis for projecting future system requirements and

limitations. The information is useful not only to the system management, but also to the grid utility management.

It will be appreciated that the invention allows connection of a wind energy system which has a potentially high output to a grid which is regarded as being weak. This is achieved in a very simple an inexpensive manner. It is envisaged that the cost of lost power output will be relatively small.

The invention is not limited to the embodiments described, but may be varied in construction and detail within the scope of the claims.

Claims

1. A wind energy system for supply of electrical power to a utility grid, the system comprising:-

a wind turbine comprising means for connection to the grid;

adjustment means for adjusting wind turbine output power;

means for sensing grid voltage and outputting a grid voltage signal; and

a controller comprising:-

an input interface for receiving the grid voltage signal;

a processor comprising means for processing the grid voltage signal to generate an output signal to limit wind turbine output power; and

an output interface for transmitting said output signal to the adjustment means.

2. A system as claimed in claim 1, wherein the sensing means also comprises means for sensing grid active power and the processor comprises means for processing a signal representing grid active power and the grid voltage signal to generate the output signal.

3. A system as claimed in claim 2, wherein the sensors comprise means for sensing three line voltages of the grid and the processor comprises means for using the maximum grid voltage value to determine the wind turbine maximum output power.

4. A system as claimed in any of claims 1 to 3, wherein the processor is initialised by storage of a default value for the maximum wind turbine output power and the processor comprises means for validating input parameters and setting the maximum wind turbine output power to the default value if validation is negative.

5. A system as claimed in claim 4, wherein the processor comprises means for determining that validation is negative if the absolute value of the short-circuit grid resistance minus the grid reactance times the tangent of the power factor angle is zero.

6. A system as claimed in any preceding claim, wherein the controller input interface comprises voltage and impedance transducers comprising means for converting sensed values to current signals.

7. A system as claimed in claim 6, wherein the input interface further comprises an analog to digital converter comprising means for converting the analog current signals to digital signals suitable for processing by the processor.

8. A system as claimed in claim 7, wherein said analog to digital converter comprises analog input modules and a bus terminal which polls the input modules for signals and routes digital signals to the processor.

9. A system as claimed in claims 7 or 8, further comprising current to voltage converters connected to convert the current signal outputs of the transducers to digital signals for monitoring of the measured values.

10. A system as claimed in any preceding claim, wherein the processor comprises means for operating in timed loops for performing screen and storage file data dumps.

11. A system as claimed in claim 10, wherein the data dumps are performed by initially calculating average values for the parameters over the period between the dumps and writing the average values.

12. A system as claimed in claims 10 or 11 wherein the processor comprises means for validating the wind turbine maximum power output value by determining that it lies within a tolerance range before outputting to the wind turbine.

13. A system as claimed in any preceding claim, wherein the output interface comprises a separate control processor connected to the processor and being programmed to output a control signal to the adjustment means.

14. A system substantially as hereinbefore described, with reference to and as illustrated in the accompanying drawings.

# The Patent Office

13

**Application No:** GB 9727394.0
**Claims searched:** 1 to 14

**Examiner:** M J Billing
**Date of search:** 19 May 1998

## Patents Act 1977
## Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H2H HAK, HAPC.

Int Cl (Ed.6): F03B 15/00, 15/02, 15/04, 15/06, 15/16; F03D 7/00, 7/02, 7/04, 7/06, 9/00; H02H 9/04; H02J 3/38; H02P 9/00, 9/02, 9/04, 9/10, 9/14, 9/30, 9/42.

Other: ONLINE - WPI.

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| A | US5225712 | (U.S. WINDPOWER) - Fig.2; Abstract | 1 |
| A | US4400659 | (BARRON) - Fig.1; Abstract | 1 |
| A | US4193005 | (UNITED TECHNOLOGIES) - Abstract | 1 |

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|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention. |
| & | Member of the same patent family | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |